ACTA ORTHOPAEDICA et TRAUMATOLOGICA TURCICA

www.aott.org.tr

Research Article

The role of 3-dimensional printed models in the management of the distal radius fractures

Aleksandr Grinčuk, Aleksas Makulavičius, Narūnas Porvaneckas, Sigitas Ryliškis, Igoris Šatkauskas, Valentinas Uvarovas

Clinic of Rheumatology, Orthopaedics Traumatology and Reconstructive Surgery,Vilnius University, Faculty of Medicine, Vilnius, Lithuania

ARTICLE INFO

Article history:
Submitted February 17, 2022
Received in revised form
July 7, 2022
Last revision received
January 5, 2023
Accepted January 19, 2023
Publication Date March 16, 2023

Keywords:
3D printed models
Inter-observer
Intra-observer
Distal radius fracture
AO/OTA classification

ORCID iDs of the authors:
A.G. 0000-0002-0782-1712,
A.M. 0000-0002-6663-9558,
N.P. 0000-0003-2790-7107,
S.R. 0000-0002-9605-5641,
I.Š. 0000-0002-2147-7989,
V.U. 0000-0002-1045-6189.

Corresponding author:
Aleksandr Grinčuk
agrincuk@gmail.com

ABSTRACT

Objective: This study aimed to compare inter- and intra-observer agreement between radiographs with 2-dimensional and 3-dimensional computed tomography scans with and without 3-dimensional printed models in the evaluation of the distal radius fracture of Association for Osteosynthesis/Orthopaedic Trauma Association type C classification.

Methods: Fifteen consecutive cases with X-Rays, 2-dimensional and 3-dimensional computed tomography reconstructions views, and 3-dimensional printed models were selected. Three-dimensional printed models of the distal radius fractures were created using 2-dimensional computed tomography scan files in Digital Imaging and Communication in Medicine format, processed with the 3-dimensional Slicer software, and segmented, creating a 3-dimensional printed model in Standard Triangle Language format. Three-dimensional models were printed using fused deposition modeling (FDM) type 3D printer Zortrax M200Plus using polylactic acid material on a scale of 1 : 1. Twenty observers were invited into the study.

Results: Intra- and inter-observer reliability was analyzed using Fleiss' kappa statistics. Overall kappa values for both groups in inter-observer agreement range from 0.113 to 0.283 and in intra-observer agreement from 0.25 to 0.545. Generally, inter-observer agreement increased with additional 3-dimensional printed models from slight to fair, and intra-observer agreement increased from fair to moderate. Surgeons' opinions about 3-dimensional printed models with Likert scale-type questions show positive overall results ranging from 8.3± 2.1 to 8.6 ± 1.4.

Conclusion: This study has shown that the inter- and intra-observer agreement with the addition of a 3-dimensional printed model for the evaluation of the distal radius fractures of Association For Osteosynthesis/Orthopedic Trauma Association C type for classification, fractures morphology, and preoperative planning tends to increase; however, improvements for an inter-observer agreement remain fair.

Level of Evidence: Level III Diagnostic Study

Introduction

Distal radius fractures are the most common injuries affecting approximately 15%-20% of all adults. Intra-articular fractures with articular surface displacement account for 50% of distal radius fractures. Approximately 25% of these are Association for Osteo synthesis/Orthopedic Trauma Association (AO/OTA) fractures.[1,2] Previous studies have revealed a correlation between anatomical joint reduction and functional clinical outcomes of distal radius fracture treatment, especially in patients with higher demands.[3,4] Complex AO/OTA type C distal radius fractures with articular displacement are a severe challenge for orthopedic surgeons.[5,6]

The AO/OTA classification is one of the most preferred classification systems for distal radius fractures.[7] In general, radiographs and computed tomography (CT) scans are used for AO/OTA type C distal radius fractures with fair-to-moderate agreement.[8,9] One study has demonstrated that the addition of 3-dimensional (3D) CT scans improves the reliability and accuracy of characterization and influences decisions for distal radius fracture treatment.[10] In contrast, another study where 3D printed models were added has reported no improvements in reliability for the recognition of fracture characteristics and classification of AO/OTA B type C distal radius fractures.[11]

In the past few years, 3D technologies have rapidly evolved in orthopedic preoperative planning because the process of creating 3D printed models has become more easily accessible at a relatively low cost. Studies have revealed that 3D printed models assist in improving orthopedic surgeons' understanding of fracture morphology and characteristics through visual and tactile experience and enable effective communication between doctors and patients.[12,13]

The classification and understanding of fracture characteristics and morphology are generally acknowledged to provide information for preoperative planning and surgical decision-making. Three-dimensional printed models can help surgeons understand fracture morphology and would assist in decision-making for the surgical approach.

This study aimed to compare inter- and intra-observer agreement between radiographs with 2-dimensional

Cite this article as: *Grinčuk A, Makulavičius A, Porvaneckas N, Ryliškis S, Šatkauskas I, Uvarovas V. The role of 3-dimensional printed models in the management of the distal radius fractures. Acta Orthop Traumatol Turc., 2023;57(1):40-45.*

DOI: 10.5152/j.aott.2023.22045

(2D) and 3D CT scans with and without 3D printed models. Further, we evaluated the surgeon's opinions on 3D printed models with Likert-scale questions. We hypothesized that the addition of 3D printed models would improve the evaluation of classification and morphology of AO/OTA type C distal radius fractures and will also assist with preoperative planning.

Materials and Methods

Study preparations

This study was approved by the Vilnius Regional Biomedical Research Ethics Committee. From February to June 2021, 15 consecutive cases of AO/OTA type C distal radius fractures from the Republican Vilnius University Hospital (the main trauma center in Lithuania) were selected for creating 3D printed models.

For each case, we collected pre- and post-reduction (after closed reduction and cast immobilization) X-Rays (posteroanterior and lateral projections), 2D (axial, sagittal, and coronal planes), 3D CT reconstructions, and 3D printed models. All 15 cases were encoded, and all views, excluding patient identifiers, were loaded to the *MikroDicom viewer, version 3.0.1* software for convenient access (Figures 1-3).

Two questionnaires were created (*Questionnaires I and II*) for orthopedic and traumatology surgeons, as well as plastic surgeons (Table 1). *Questionnaire I* was used to evaluate the X-Ray, 2D, and 3D CT views. *Questionnaire I* comprises 2 sections as follows: the first section for the fracture AO/OTA classification and the second section for the preoperative planning, which comprises 3 questions. *Questionnaire II* was used to evaluate the X-Rays, 2D and 3D CT views, and 3D printed model. *Questionnaire II* has the same 2 sections as *Questionnaire I* with an additional third section, comprising 6 10-point Likert scale response type questions regarding 3D printed models, where 1 indicates the worst and 10 indicates the best evaluation.[14] The questionnaires were uploaded to the online platform *Google forms* with AO/OTA type C distal radius fractures.[15]

Creating a 3-dimensional printed model

Three-dimensional printed models of distal radius fractures without carpus were created in the Republic Vilnius University Hospital in Orthopedic and Traumatology Centers by an orthopedic and traumatology surgeon. Two-dimensional CT scans with a 0.5-mm slice thickness were used and the scanned files in digital imaging and communication in medicine (DICOM) format were exported from the hospital's *MedDream software, version 7.6.0*. The DICOM files were imported to the *3D Slicer*, *version 4.10.2* software, and segmented using level tracing technique in CT "bone" window in coronal, sagittal, axial planes creating 3D digital models of the distal radius fractures. Global 50% smoothing was applied, and 3D digital models were exported to the files in standard triangle language (STL) format. The STL files were exported to *Z-suite, version 2.16.2* software for the fused deposition modeling 3D printer *Zortrax M200Plus* (Olsztyn,

Figure 1. X-Ray posteroanterior (PA) view.

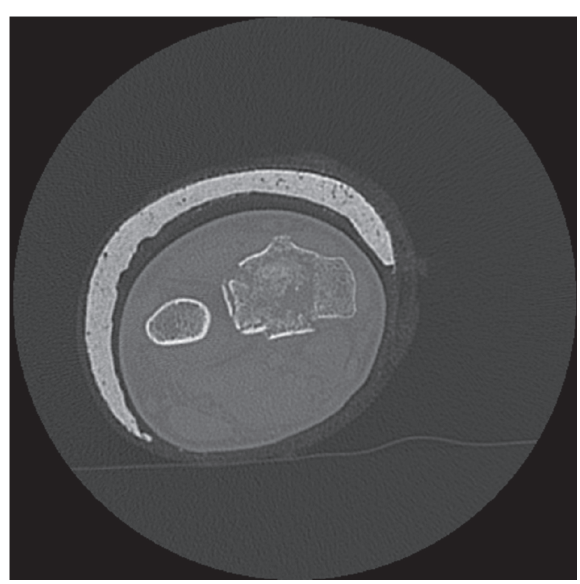

Figure 2. CT 2D axial view. CT, computerized tomography; 2D, 2 dimension.

HIGHLIGHTS

- Three-dimensional (3D) technologies have rapidly evolved in orthopedic preoperative planning because the process of creating 3D printed models has become more easily accessible at a relatively low cost. This study aimed to investigate the effect of using 3-dimensional printed models in evaluating AO type C distal radius fractures.
- The results show that the 3D printed model increases the inter-observer agreement from slight to fair, and intra-observer agreement from fair to moderate for evaluating classification and fracture morphology of AO Type C distal radius fractures.
- The results from this study indicate that the 3D printed model improves inter- and intra-observer agreements for evaluating classification and fracture morphology of AO Type C distal radius fractures and assists in preoperative planning with acceptable results. Moreover, it may be a practical addition as a modern teaching tool for distal radius intra-articular fractures.

Figure 3. 3D CT view. CT, computerized tomography; 3D, 3 dimension.

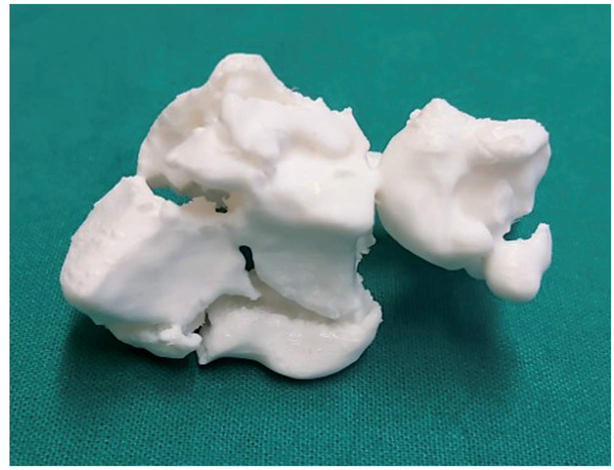

Figure 4. Printed 3D model on a scale of 1 : 1, without support material. 3D, 3 dimension

Poland). The *Z-suite* manufacture settings were applied for printing the 3D models using polylactic acid (PLA). The following settings were set for smart bridges and lite support (GAP XY, 0.68 mm; density, 4.0 mm): a nozzle diameter of 0.4 mm, layer thickness of 0.29 mm, print quality was set to high with an infill density of 50%, and support was automatically generated with ≥30° angle. The 3D models were oriented horizontally to minimize material use. The 3D digital models were generated, exported in the *Zortrax Printing Code* file format, and loaded onto a *Zortrax M200Plus* 3D printer. The 3D models were then printed on a 1 : 1 scale using PLA material, with plastic extrusion at 210°C and a platform at 30°C. Support materials were mechanically cleared (Figure 4).

Intra- and inter-observer study design

Twenty observers from the Republic of Vilnius University Hospital were invited to participate in this study. The observers were divided into 2 groups to compare the results. The first group (expert group) included orthopedic and traumatology surgeons and plastic surgeons who performed open reduction and internal fixation of distal radius fractures in at least 20 cases yearly. The second group comprising general orthopedic and traumatology surgeons had a minimum of 5 years of postgraduate clinical practice.

Round I: Initially, a link to *Questionnaire I* with brief instructions on how to operate *Google forms* and *MikroDicom* was sent by e-mail to the observers, to ensure a quick and easy process. All the observers were familiar with the AO/OTA classification. After each case was encoded, the observers were individually asked to answer questions from each section of *Questionnaire I* without any time restrictions. Once submitted, their answers were not altered. Subsequently, 2 weeks later, a link to *Questionnaire II* was e-mailed to the observers. Fifteen cases were randomly arranged, with the observers provided access to the 3D printed model to hold in their hands and rotate in all directions. After each case, the observers were asked to answer the questions in *Questionnaire II.*

Round II: After 6-8 weeks, all the observers repeated the process for all 15 cases in random order.

Statistical analyses

Intra- and inter-observer reliabilities were analyzed using Fleiss' kappa statistics. Fleiss' kappa was used to measure agreement between multiple raters on categorical variables. Calculated kappa coefficients were interpreted according to the Landis and Koch criteria, in which coefficients from 0.0 to 0.2 indicate slight agreement, 0.21 to 0.40 indicate fair agreement, 0.41 to 0.60 indicate moderate agreement, 0.61 to 0.80 indicate substantial agreement, and 0.81 to 1.0 indicate almost perfect or perfect agreement.[16] Bootstrap (based on 1000 replicates) was used to calculate the standard error, z-statistics,

Table 1. Questionnaires I and II

	Questions	Options
Section I	Classify distal radius fracture according to the AO/OTA classification	C1, C2, C3
Section II	1. How many fragments are dislocated (gap > 2 mm, joint surface step-off >2 mm)?	≤2, 3, ≥4
	2. How many fragments have to be fixed (radial styloid, volar lunate facet, dorsal lunate facet, volar rim, dorsal rim, and central articular impaction)?	≤2, 3, ≥4
	3. Surgical approach and fixation?	Volar plating, dorsal plating, combined (dorsal and volar) plating
Questionnaire II—Section III	Questions	Likert scale from 1 to 10
	1. Evaluate the quality of the 3D printed models — Do 3D printed models correspond to radiographic and CT scan images?	
	2. Did the 3D printed model provide additional information on fracture morphology?	
	3. Will the 3D printed model help you with the surgery?	
	4. Would you want to use a 3D printed model for preoperative planning in the future?	
	5. Will the 3D printed model help you more easily in providing information to the patient regarding fractures and explaining the surgical plan?	
	6. Are 3D printed models useful in orthopedic and traumatology surgery?	

AO/OTA, Association For Osteosynthesis/Orthopedic Trauma Association; 3D, 3 dimension.

95% CI, and P values to compare the kappa values between the 2 groups. The level of significance was set at $\alpha = 0.05$.

The 10-point Likert scale data questions are summarized as means with standard deviations. The positive responses for the question points were 6, 7, 8, 9, and 10, and 5 was considered a mid-point to neutral opinion.[17]

Statistical analyses were calculated using the R software, version 4.0.4.

Results

Inter-observer agreement was calculated after round I. In both groups, the kappa values increased with an additional 3D printed model with ranges: in group I from 0.118 (slight) to 0.295 (fair) and in group II from 0.103 (slight) to 0.29 (fair) agreement compared to X-Ray, 2D, and 3D views, without significant difference ($P > .05$).

Intra-observer agreement was calculated after round II. In group I, the kappa values improved for the AO/OTA classification and for the question "How many fragments have to be fixed?" with an additional 3D printed model with fair to moderate agreement ($P < .05$). No significant improvement in kappa values was observed for the questions "How many fragments are dislocated?" and "Surgical approach and fixation?" ($P > .05$). In group II, the kappa values improved with an additional 3D printed model, ranging from 0.185 (slight) to 0.554 (moderate) agreement compared to X-Ray, 2D, and 3D views ($P < .05$), except for the question "Surgical approach and fixation?" The kappa values increased from slight to moderate, without significant difference in kappa values between the 2 groups ($P > .05$).

The overall kappa values ranged in inter-observer agreement from 0.113 (slight) to 0.283 (fair) and intra-observer agreement from 0.25 (fair) to 0.545 (moderate). In general, overall inter-observer agreement improved for the questions "How many fragments are dislocated?" and "How many fragments have to be fixed?" with an additional 3D printed model from slight to fair ($P < .05$) (Table 2). Intra-observer agreement improved from fair to moderate ($P < .05$), except for the question "Surgical approach and fixation?" ($P > .05$) (Table 3).

After completing both rounds, the 10-point Likert scale data were calculated for 6 questions. In general, both groups had similar positive responses, ranging from 7.9 ± 1.6 to 8.7 ± 1.4. The overall responses ranged from 8.3 ± 2.1 to 8.6 ± 1.4 for all 6 questions (Table 4).

Discussion

In the past few years, 3D printing technology has been scientifically validated in the following orthopedic and traumatology fields for the evaluation of fractures: classification systems, morphology, and characteristics, which theoretically leads to improvements in preoperative planning.[10,12,18] However, the lack of studies illustrating improvements in the reliability of using 3D printed models for distal radius fractures discourages the wide use of 3D printed models. Nevertheless, 3D printed models are becoming more popular because they can be visualized intuitively, which improves the classification of proximal and distal humeral and acetabular fractures. Furthermore, these recent studies have suggested the clinical potential for developing treatment plans.[19-21]

The AO/OTA classification remains the primary classification for distal radius fractures.[22] The reported kappa values for AO/OTA

Table 2. Overall inter-observer agreement

	X-Rays, 2D, 3D CT			X-Rays, 2D, 3D CT, and 3D printed model			
	Kappa (category)	95% CI	*P*	Kappa (category)	95% CI	*P*	*P**
AO/OTA classification	0.113 (slight)	0.047- 0.206	<.001	0.273 (fair)	0.148-0.439	<.001	.053
How many fragments are dislocated?	0.083 (slight)	0.042-0.141	<.001	0.256 (fair)	0.182-0.366	<.001	.001
How many fragments have to be fixed?	0.114 (slight)	0.049-0.199	<.001	0.283 (fair)	0.175-0.424	<.001	.027
Surgical approach and fixation	0.174 (slight)	0.046-0.337	<.001	0.273 (fair)	0.057-0.563	<.001	.505

**P*-value for the difference of the kappa values of each of the comparison groups.
2D, 2 dimension; 3D, 3 dimension; CT, computerized tomography.

Table 3. Overall intra-observer agreement

	X-Rays, 2D, 3D CT			X-Rays, 2D,3D CT, and 3D printed model			
	Kappa (category)	95% CI	*P*	Kappa (category)	95% CI	*P*	*P**
AO/OTA classification	0.25 (fair)	0.156-0.352	<.001	0.517 (moderate)	0.431-0.603	<.001	<.001
How many fragments are dislocated?	0.273 (fair)	0.182-0.365	<.001	0.509 (moderate)	0.429-0.591	<.001	<.001
How many fragments have to be fixed?	0.296 (fair)	0.207-0.392	<.001	0.25 (moderate)	0.464-0.634	<.001	<.001
Surgical approach and fixation	0.316 (fair)	0.207-0.428	<.001	0.459 (moderate)	0.35-0.578	<.001	.08

**P*-value for the difference of the kappa values of each of the comparison groups.
2D, 2 dimension; 3D, 3 dimension; CT, computerized tomography.

Table 4. Results for q*uestionnaires II* section III.

Questions	Group I	Group II	Overall
1. Evaluate the quality of the 3D printed models — Do 3D printed models correspond to radiographic and CT scan images?	8.6 ± 1.4	8.6 ± 1.5	8.6 ± 1.4
2. Did the 3D printed model provide additional information on fracture morphology?	8.3 ± 1.7	8.6 ± 1.5	8.4 ± 1.6
3. Will the 3D printed model help you with the surgery?	7.9 ± 1.6	8.7 ± 1.4	8.3 ± 1.6
4. Would you want to use a 3D printed model for preoperative planning in the future?	8.2 ± 1.6	8.7 ± 1.4	8.5 ± 1.5
5. Will the 3D printed model help you more easily in providing information to the patient regarding fractures and explaining the surgical plan?	8.6 ± 2.1	8.1 ± 1.9	8.3 ± 2.1
6. Are 3D printed models useful in orthopedic and traumatology surgery?	8.4 ± 1.6	8.5 ± 1.5	8.5 ± 1.5

2D, 2 dimension; 3D, 3 dimension; CT, computerized tomography.

classification of the groups in the literature were 0.23-0.48 and 0.29-0.65 for inter- and intra-observer agreements, respectively.[5,23] Meanwhile, our study demonstrated an increase in kappa values with the addition of 3D printed models in inter-observer agreement from 0.113 (slight) to 0.273 (fair) and in intra-observer agreement from 0.25 (fair) to 0.517 (moderate) according to the Landis and Koch criteria. Although our kappa coefficients are not high, they are comparable to those of other studies, in which the kappa values were 0.17-0.46.[24]

Compared to Langerhuizen et al.[11] who observed no improvement in the reliability for classifying fracture characteristics of AO/OTA types B and C distal radius fractures with 3D printed models, we achieved satisfactory results for evaluating the morphology and preoperative planning for AO/OTA type C distal radius fractures, with an improved overall intra-observer agreement from fair to moderate for the AO/OTA classification and questions: "How many fragments are dislocated?" and "How many fragments have to be fixed?" ($P < .05$). In the overall inter-observer agreement, the kappa values improved from slight to fair for the questions "How many fragments are dislocated?" and "How many fragments have to be fixed?" ($P < .05$).

The prepared Likert scale-type questions for evaluating surgeons' opinions on 3D printed models in distal radius fractures may be subjective. Chen et al[13] have proposed their questions for the evaluation of "usefulness of 3D printing models," with a mean overall result of 6.7 ± 1.4. Our findings of the surgeon's opinions regarding 3D printed models in distal radius fractures demonstrate more satisfactory results, with overall means for questions ranging from 8.3 ± 2.1 to 8.5 ± 1.5.

Intra-articular distal radius fractures are complex and challenging for surgeons. In our study, the inter-observer kappa values ranged from slight to fair and were smaller than the intra-observer kappa values, which ranged from fair to moderate. Thus, the management of distal radius intra-articular fractures may be subjective and rely on the surgeon's experience.

In our study, 3D CT scans were presented with carpal bones, so the axial part of the joint could not be inspected. Three-dimensional printed models were created without them, so the evaluation of the distal radius articular surfaces could have been more accurate. Additionally, 3D CT scans are still viewed on a 2D computer screen and may not represent an actual view of size and depth. Because of these limitations, 3D printed models may provide a better understanding of distal radius complex fractures than 3D CT scans.

Our study was designed to minimize the risk of observers remembering the individual cases between evaluations by introducing a 2-week delay between the first and second parts of the evaluation process and a 2-month interval between the first and second rounds. Additionally, each of the 15 cases was presented randomly to each observer for evaluation.

Nevertheless, our study had several limitations. First, we did not include residents in the evaluation process because our trauma center is not familiar with 3D printed models. Second, most observers evaluated the 3D printed models for the first time. Third, this study mainly investigated the situation with experienced orthopedic and traumatology surgeons. Finally, some studies have reported that residents do not improve the observers' agreement.[23]

All the 3D printed models were created by a single orthopedic and traumatology surgeon without assistance. The 3D printed models did not visualize small fracture lines and dislocations that were <0.4-mm thick. The fracture lines were then merged and smoothed. These changes may have influenced the evaluation process and the observer's responses because these fracture lines can be observed in the 2D CT views. Nevertheless, this is a minor disadvantage because the 3D printed models can be intuitively visualized in 3D, thus providing the opportunity to rotate the distal radius fracture in all directions and overcoming these disadvantages.

In our study, we did not separately compare the observers' agreement between X-Rays, 2D-3D CT scans, and 3D printed models because radiographs and CT scans are commonly used for the diagnosis and preoperative planning of distal radius intra-articular fractures. Three-dimensional printed models only provided additional information on fracture morphology and characteristics. In clinical practice, surgeons cannot rely only on 3D-printed models alone.

Our study's sample size was not calculated due to the limitation of available distal radius fracture cases with good-quality 3D CT scans. However, the obtained P-values ($P < .001$) indicate that the kappa values are significantly different from "0."

In conclusion, the inter- and intra-observer agreements with the addition of a 3D printed model for evaluating AO/OTA type C distal radius fractures for classification, fracture morphology, and preoperative planning tend to increase; however, the improvements for inter-observer agreement remain fair. Three-dimensional printing may also be a practical addition to modern teaching tools for distal radius intra-articular fractures. Further investigations are needed to evaluate the potential implications of 3D printed models in clinical practice for the management of complex distal radius intra-articular AO/OTA type C fractures.

Ethics Committee Approval: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Vilnius Regional Biomedical Research Ethics Committee (approval No. 2021/01-1299-777).

Informed Consent: Written informed consent was obtained from all subjects before the study.

Author Contributions: Concept – A.G., V.U.; Design – A.G., I.Š, S.R.; Supervision: A.M., N.P., V.U.; Materials – A.G., I.Š., S.R.; Data Collection and/or Processing – N.P., V.U., A.M.; Analysis and/or Interpretation – A.M., I.Š., N.P.; Literature Review – I.Š., S.R.; Writing – A.G., V.U.; Critical Review – N.P., S.R., A.M.

Acknowledgments: The authors thank all staff in the Republican Vilnius University Hospital.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study had received no financial support.

References

1. Bentohami A, Bosma J, Akkersdijk GJM, van Dijkman B, Goslings JC, Schep NWL. Incidence and characteristics of distal radial fractures in an urban population in the Netherlands. *Eur J Trauma Emerg Surg.* 2014;40(3):357-361. [CrossRef]
2. Rundgren J, Bojan A, Mellstrand Navarro C, Enocson A. Epidemiology, classification, treatment and mortality of distal radius fractures in adults: an observational study of 23,394 fractures from the national Swedish fracture register. *BMC Musculoskelet Disord.* 2020;21(1):88. [CrossRef]
3. Raudasoja L, Vastamäki H, Raatikainen T. The importance of radiological results in distal radius fracture operations: functional outcome after long-term (6.5 years) follow-up. *SAGE Open Med.* 2018;6:2050312118776578. [CrossRef]
4. Cai L, Zhu S, Du S, et al. The relationship between radiographic parameters and clinical outcome of distal radius fractures in elderly patients. *Orthop Traumatol Surg Res.* 2015;101(7):827-831. [CrossRef]
5. Teunis T. Distal radius fractures: what determines the outcome after surgery? *Ned Tijdschr Traumachirurg.* 2016;24(4):22-23. [CrossRef]
6. Zhang X, Hu C, Yu K, et al. Volar locking plate (VLP) versus non-locking plate (NLP) in the treatment of die-punch fractures of the distal radius, an observational study. *Int J Surg.* 2016;34:142-147. [CrossRef]

7. Kleinlugtenbelt YV, Groen SR, Ham SJ, et al. Classification systems for distal radius fractures. *Acta Orthop*. 2017;88(6):681-687. [CrossRef]
8. Jayakumar P, Teunis T, Giménez BB, Verstreken F, Di Mascio L, Jupiter JB. AO Distal radius fracture classification: global perspective on observer agreement. *J Wrist Surg*. 2017;6(1):46-53. [CrossRef]
9. Mulders MaM, Rikli D, Goslings JC, Schep NWL. Classification and treatment of distal radius fractures: a survey among orthopaedic trauma surgeons and residents. *Eur J Trauma Emerg Surg*. 2017;43(2):239-248. [CrossRef]
10. Harness NG, Ring D, Zurakowski D, Harris GJ, Jupiter JB. The influence of three-dimensional computed tomography reconstructions on the characterization and treatment of distal radial fractures. *J Bone Joint Surg Am*. 2006;88(6):1315-1323. [CrossRef]
11. Langerhuizen DWG, Doornberg JN, Janssen MMA, Kerkhoffs GMMJ, Jaarsma RL, Janssen SJ. Do 3-D printed handheld models improve surgeon reliability for recognition of intraarticular distal radius fracture characteristics? *Clin Orthop Relat Res*. 2020;478(12):2901-2908. [CrossRef]
12. Bizzotto N, Tami I, Santucci A, et al. 3D Printed replica of articular fractures for surgical planning and patient consent: a two years multi-centric experience. *3D Print Med*. 2015;2(1):2. [CrossRef]
13. Chen C, Cai L, Zheng W, Wang J, Guo X, Chen H. The efficacy of using 3D printing models in the treatment of fractures: a randomised clinical trial. *BMC Musculoskelet Disord*. 2019;20(1):65. [CrossRef]
14. Courser MW, Lavrakas PJ. Item-nonresponse and the 10-point response scale in telephone surveys. *Surv Pract*. 2012;5(4):1-5. [CrossRef]
15. Meinberg EG, Agel J, Roberts CS, Karam MD, Kellam JF. Fracture and dislocation classification Compendium-2018. *J Orthop Trauma*. 2018;32(suppl 1):S1-S170. [CrossRef]
16. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174. [CrossRef]
17. Joshi A, Kale S, Chandel S, Pal D. Likert scale: explored and explained. *Br J Appl Sci Technol*. 2015;7(4):396-403. [CrossRef]
18. Brouwers L, Pull ter Gunne AF, de Jongh MAC, et al. The value of 3D printed models in understanding acetabular fractures. *3D Print Addit Manuf*. 2018;5(1):37-46. [CrossRef]
19. Cocco LF, Aihara AY, Franciozi C, Dos Reis FB, Luzo MVM. Three-dimensional models increase the interobserver agreement for the treatment of proximal humerus fractures. *Patient Saf Surg*. 2020;14:33. [CrossRef]
20. Cocco LF, Yazzigi JA, Kawakami EFKI, Alvachian HJF, Dos Reis FB, Luzo MVM. Inter-observer reliability of alternative diagnostic methods for proximal humerus fractures: a comparison between attending surgeons and orthopedic residents in training. *Patient Saf Surg*. 2019;13:12. [CrossRef]
21. Gregory TM, Alkhaili J, Silvera J, Vitis B, Chaves C, Gregory J. Three-dimensional (3D) printing technology for the classification of complex distal humerus fractures. *Ann Joint*. 2018;3:96-96. [CrossRef]
22. van Buijtenen JM, van Tunen MLC, Zuidema WP, et al. Inter- and intra-observer agreement of the AO classification for operatively treated distal radius fractures. *Strateg Trauma Limb Reconstr*. 2015;10(3):155-159. [CrossRef]
23. Plant CE, Hickson C, Hedley H, Parsons NR, Costa ML. Is it time to revisit the AO classification of fractures of the distal radius? Inter- and intra-observer reliability of the AO classification. *Bone Joint J*. 2015;97-B(6):818-823. [CrossRef]
24. Porrino JA, Maloney E, Scherer K, Mulcahy H, Ha AS, Allan C. Fracture of the distal radius: epidemiology and premanagement radiographic characterization. *AJR Am J Roentgenol*. 2014;203(3):551-559. [CrossRef]